Sequential Time-bin Entanglement Generation Using Periodically Poled KTP Waveguide[1]

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Abstract: We demonstrated non-degenerate sequential time-bin entanglement using periodically poled KTP waveguide at a repetition rate of 1 GHz. The wavelengths of signal and idler are 895 and 1310 nm. The two-photon-interference-fringe visibility is 79 %.

OCIS codes: (270. 5565) Quantum optics, quantum communication; (190.4410) Nonlinear optics, parametric processes.

1. Introduction

Entanglement is important for the realization of quantum communication, quantum teleportation and quantum computation. For a fiber-based quantum communications system, time-bin entanglement, or pulsed energy-time entanglement [1] is more suitable than polarization entanglement, since it is not sensitive to polarization changes in optical fibers. The original time-bin entanglement approach is to use two consecutive laser pulses generated by an unbalanced interferometer to pump a nonlinear media. During the process, the two pulses have a certain probability to generate a photon pair by parametric down-conversion and implement the time-bin entangled photon pairs [1, 2]. When a laser pulse train is used to pump the nonlinear media, and the condition $T_c >> \tau >> \tau_p$ (where T_c is the coherence time of pump beam, τ is the pulse interval, τ_p is the pulse duration) is satisfied, a sequential time-bin entanglement can be generated [3, 4]. The sequential time-bin entanglement scheme does not need an interferometer at the source side, and can achieve high-repetition rates which are more suitable for quantum communication. Several groups have successfully implemented high repetition rate sequential time-bin entanglement at the 1550 nm band using four-wave-mixing in dispersion shifted fiber [3] and periodically-poled $LiNbO_3$ (PPLN) waveguides [4]. In this paper, we report a non-degenerate sequential time-bin entanglement generation using a periodically-poled potassium titanyl phosphate (PPKTP) waveguide at a repetition rate of 1 GHz. One wavelength of the non-degenerated photon pairs is 895 nm, which is resonant with the transition line of Cs atoms and also compatible with 850-nm local optical network. The conjugate wavelength is 1310 nm, a suitable wavelength for long distance quantum communication in coexistence with conventional 1550-nm signals in current optical networks.

2. Experimental setup

Figure 1 schematically shows the experimental setup.

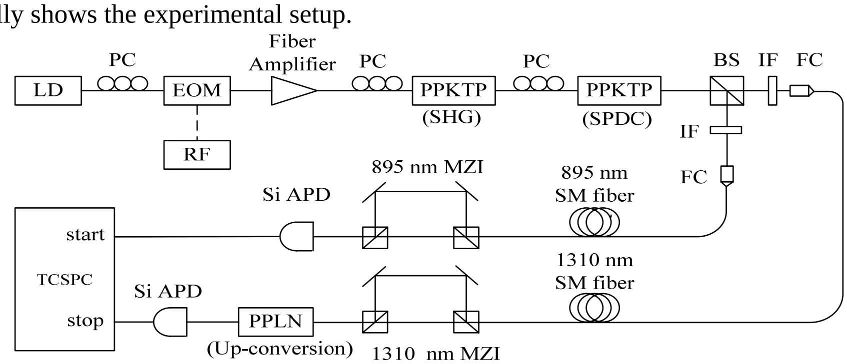

Fig. 1. Diagram of the experimental setup. LD: 1064-nm CW laser Diode; EOM: Electric-optic Modulator; RF: RF pulse generator; PC: Polarization controller, PPKTP: Periodically-poled KTP waveguide; BS: 895/1310 nm Dichroic beam splitter; IF: Interference Filter; FC: Fiber Collimator; MZI: Mach-Zehnder interferometer; Si-APD: Silicon based avalanche photo diode; PPLN: Periodically-poled $LiNbO_3$ waveguide for frequency up-conversion; TCSPC: time-correlated single photon counting module.

A CW 1064-nm laser beam was modulated into a 1-GHz pulse train with a FWHM of 330 ps by an amplitude modulator, and the pulses are then further amplified by a fiber amplifier that can control the output power. A

[1] The identification of any commercial product or trade name does not imply endorsement or recommendation by the National Institute of Standards and Technology.

polarization controller (PC) is used to launch the proper polarization into the first PPKTP, which is used for the second harmonic generation (SHG) of 532-nm pump pulses. The pump pulses are then coupled into a 532-nm single-mode fiber, which will reduce 1064 nm light and other noise from the fiber amplifier. The second PPKTP waveguide is periodically poled for the spontaneous parametric down conversion (SPDC) of 532 nm to 1310 nm and 895 nm. The 895-nm and 1310-nm photons are separated using a dichroic beam splitter, and then coupled into 895-nm and 1310-nm single mode fibers, respectively. Bandpass filters are used to reduce the residential pump photons and other noise. Two free-space 1-ns unbalanced Mach-Zehnder interferometers are used to measure the two-photon-interference-fringe visibility. The phases of the interferometers can be adjusted by a piezo nanopositioning stage. A silicon-based avalanche photo diode (APD) (SPCM-AQR-14) is used to measure photons at 895 nm, and a PPLN waveguide-based up-conversion unit with another silicon-based APD [5] is used for photons at 1310 nm. The detected signals are fed into a time-correlated single photon counting module (TCSPC) for coincidence measurement.

3. Results and discussion

In the experiment, amplified 1064-nm laser pulses (average power of 180 mW) are coupled into the SHG frequency doubler and 0.2 mW 532-nm laser pulses are coupled into 532-nm single mode fiber, and then guided into the second PPKTP for SPDC. Fig. 2 (a) shows the histogram of coincidence photon pairs, directly detected without passing through the interferometers. The measured coincidence photon pair flux is 2600 Hz in a 500-ps window. From the histogram, the timing jitter (FWHM) of the correlated photon pairs is 500 ps, which is mostly due to the timing jitter of two Si-APDs. Piezo nanopositioning stages are used to set and vary the phase of both the signal interferometer (895 nm) and the idler interferometer (1310 nm). To determine the two-photon-interference-fringe visibility of the entangled photon pairs, we measured the photon coincidence through the interferometers, in which we fixed the phase for the signal interferometer (895 nm) and varied the phase for the idler interferometer (1310 nm). To demonstrate entanglement, we set two different fixed phases for the signal and got two interference patterns with the varied phase of the idler, as shown in fig. 2 (b). The average visibility of the two curves is 79% without subtraction of noise, which is above the visibility required for violation of the Bell inequality. The imperfection of the visibility is mainly caused by the timing jitter of the detectors and the imperfect visibility of the interferometers.

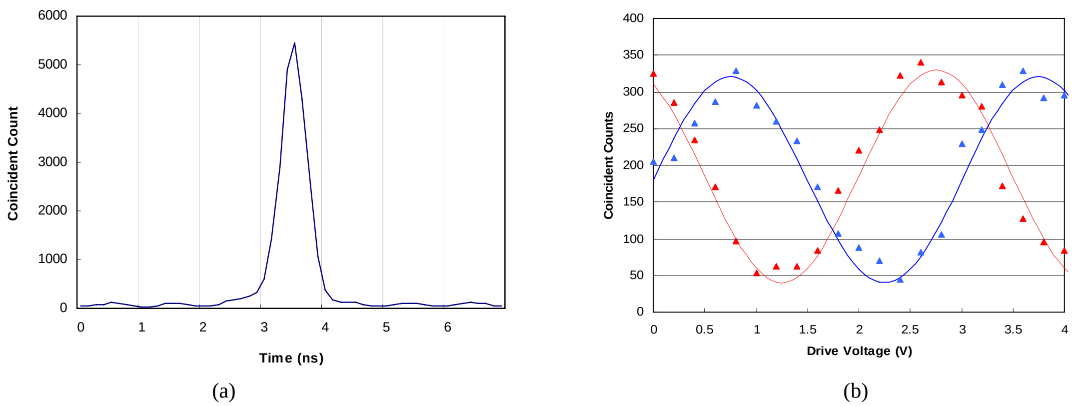

Fig. 2. (a) Histogram of the coincidence counts of photon pairs. The counts are collected in a 10 second interval. (b) Coincidence interference fringes measured in the experiments. Red and blue triangles are the coincidence counts when the piezo drive voltages of 850 nm interferometer are 0 and 1 volt respectively. The coincidence counts are collected in 500 ps window in a 10 second interval.

In conclusion, we have implemented a sequential time-bin entanglement source using PPKTP waveguide. The signal and idler photons are 895 nm and 1310 nm, which are suitable for local and long distance optical networks, respectively. The coincidence count flux and the visibility can be increased by improving the interferometers and the timing jitter of the detectors.

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